USER INTERFACE ISSUES IN SUPPORTING
HUMAN-COMPUTER INTEGRATED SCHEDULING

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ABSTRACT

A major problem in designing user interfaces for scheduling systems is one of allowing the human to become an integral part of the system. The human role in scheduling extends beyond the simple tasks of providing the input and accepting the output. Because of the inherent intractability of most real-world scheduling problems, intelligence must be incorporated into the scheduling process in order to reach an acceptable solution in a reasonable amount of time. Artificial Intelligence research has concentrated on identifying algorithms and heuristics for this purpose. However, interfaces which allow the scheduler to take advantage of human intelligence and allow the user insight into and influence over the planning process are also needed.

Enhanced interfaces support transitioning to a human-computer integrated mode of scheduling. This paper explores the user interface problems encountered with the Operations Mission Planner project at the Jet Propulsion Laboratory. OMP uses a unique iterative approach to planning which places additional requirements on the user interface, particularly to support system development and maintenance. These requirements are necessary to support the concepts of heuristically controlled search, in-progress assessment, and iterative refinement of the schedule. This paper presents the techniques used to address the OMP interface needs.

BACKGROUND

The Operations Mission Planner (OMP) is a multi-year research project currently in its third year. The goal of this project is to use Artificial Intelligence techniques to create an intelligent, automated planning and scheduling system. The need for advanced user interface capabilities to support this goal has been recognized. In addition to providing the general user with a means of interfacing with OMP, the user interface must also incorporate advanced features which support the special needs of system developers and maintainers [Becker 1987]. These include facilities to assist in the identification and development of heuristics, in debugging the planning logic, and in evaluating the quality of the schedule produced. The following sections identify problems in user interface design which have surfaced due to research currently underway on the OMP project along with the techniques being used to address those problems.

GENERAL PROBLEM DESCRIPTION

The interfaces to existing planning and scheduling systems range from those which provide only the final results of the scheduling process (e.g. Deviser [Vere 1983], RALPH [Webb and Yates 1987]) to those which provide incremental results during execution (e.g. PLAN-IT [Biefeld 1986], OMP-I). However, the information and rules that the planner used to reach the decisions are embedded deep in the planning process and are generally unavailable during execution. A functional user interface

must provide a means of looking "behind the scenes" during actual scheduling in order to enable the user to understand the motivations for performing particular scheduling actions.

Current modalities for in-progress interaction limit the user to performing direct scheduling tasks (e.g. moving a task, deleting a task, specifying a task breakdown, or choosing from a program-generated set of predefined control options) during an actual scheduling run. For example, the interactive mode for OPIS system [Smith 1988], consists of several opportunities during the control cycle for the user to pick from a list of options. The user is unable to make small, real-time changes to the scheduling heuristics and is therefore unable to directly influence how the scheduler makes future, automated decisions without editing the code.

When the user makes a direct change to the schedule, the automated scheduler has no insight into the user's decision making process. The scheduler is left without a means of interpreting the significance of the user's action. If a user moves a task to a specific location, is the user indicating a preference or an absolute? Under what circumstances, if any, can the scheduler move that task?

Real-time evaluation of the quality of the schedule by the user requires advanced interface techniques. If the user only sees the results of the scheduling efforts up to a given point, he has only a limited feel for how the schedule is progressing. Have problem areas been identified and resolved? Has the schedule really improved -- or is it at an impasse? Is the schedule "good enough"?

The design philosophy for many user interfaces is to present the user with as much information as possible on the status of the system. Such interfaces often cause the user to suffer from data overload. Too many tasks, squeezed into too little space, using a representation which is difficult to interpret for complex problem domains, results in inefficient interfaces [Schneiderman 1987]. Incorporating additional modalities, without special consideration for form and

functionality, results in unusable interface designs. Advanced techniques which filter user information to support only the function the user is performing, and which reduce the clutter on the screen without reducing information content, are vital in addressing the problem of data overload.

These problems have surfaced as a result of research currently being performed at the Jet Propulsion Laboratory in the areas of planning and scheduling. While the focus of the research has been on automating the scheduling process, it has become quite evident that improved methods of user interaction with the system are essential for system development and are highly desirable for acceptance of any resulting system by the user community. Because the interface issues are tightly coupled to the planning and scheduling research, it is important to understand some of the unique underlying concepts of the Operations Mission Planner.

PROBLEM DOMAIN

The Operations Mission Planner problem is one of resource allocation in a highly over-subscribed, under-constrained domain. There are three main areas of research in OMP: iterative planning, multiple control heuristics, and chronologies [Atkinson, et.al. 1988].

OMP is an iterative planner which progresses by making a series of passes over the schedule [Biefeld and Cooper 1988a]. Each pass further refines the schedule by performing a deeper, but more narrowly focused search. The purpose of these iterations is to use the information gathered during previous passes to guide the current pass. This information is kept in a variety of data objects, referred to collectively as chronologies. The chronologies are used by various heuristics which assess the state of the schedule, control the focus of the schedule and perform scheduling actions [Biefeld and Cooper 1988b].

OMP iterates through several phases to complete a schedule. Each phase has a specific goal, focus, and associated heuristics, and consists of several passes through the

schedule. OMP first uses simple and very fast heuristics to load the schedule. In the next phase, it focuses on identifying resource bottlenecks. Once these bottlenecks have been identified, OMP switches to more powerful scheduling heuristics to resolve the conflicts existing in the bottleneck regions. The final phase of plan generation consists of "optimizing" the schedule. Since the system is so greatly over-subscribed, OMP uses this phase to maximize the number of tasks performed by the schedule.

OMP must also react in real-time to events occurring during schedule execution. An additional phase, the Event Handler, is responsible for initiating replanning activities based on its assessed impact of the event on the schedule. Since OMP is an iterative system, the Event Handler's primary function is identifying in which of the generation phases to reinitiate planning. Information gathered throughout the scheduling process remains available for the scheduler to use. The reinitiation process depends upon the severity of the event (e.g. simple task insertion vs. recovery from major resource failure) [Biefeld and Cooper 1990].

Each phase has different heuristics associated with it. These heuristics control the availability of scheduling actions, the basis for choosing between scheduling options, assessment techniques, guidelines for conducting search, and control mechanisms for identifying and progressing to the next phase.

Each major research area of OMP highlights pertinent user interface problems. How do we depict the iterative process to the users? The user must be allowed to interact with the heuristics to guide the scheduling process. How do we enable the system to interpret human intervention in the scheduling process? System developers and maintainers are responsible for identifying, testing, and incorporating new heuristics. How do we provide insight into the development of chronologies and the scheduling processes so the user can formulate new heuristics? These functionalities must fit into the user interface

without overwhelming the user.

TECHNIQUES

Both the automated and human portions of a system such as OMP must be considered in defining the operational system [Potosnak 1987]. The OMP functional analysis identified the proposed breakdown of tasks between the automated and human segments. The automated segment is responsible for the process of scheduling, while the user is responsible for monitoring the scheduling process and for improving or creating new aspects of the system (e.g. heuristics). The automated scheduler should be able to develop, assess, and modify the schedule without the benefit of any additional input from the user. It must, however, be able to incorporate user direction when provided.

Since the user is responsible for identifying new heuristics and scheduling algorithms, he is ultimately responsible for assessing the quality of the schedule, and monitoring its execution. With the appropriate tools, the user can also play a vital role in identifying problems during the scheduling process, providing guidance, and directly manipulating the schedule.

Chronologies

In order to identify new heuristics and scheduling algorithms, the user must have insight into the iterative planning process. In order to do this, we must first provide insight into the development of chronologies. OMP's overall planning paradigm is based on empirical analysis of expert human schedulers [Biefeld 1986]. Initially, heuristics were developed to emulate the types of behavior exhibited by these experts. Additional heuristics have been discovered by watching OMP execute and focusing on specific parameters of potential importance. Observations of changes in the schedule representation as the scheduler progresses and off-line analysis of OMP performance for test cases revealed heuristics which decide how to configure resources, make a task-resource assignment, and determine the area of the

schedule to work on next.

While initial analysis has proved useful, the level of complexity OMP will entail requires the use of tools which will make the observation, analysis, and synthesis tasks easier and more efficient to perform. Rather than looking at chronologies after the fact, we need to observe them as they are being built. The best method for doing this depends on the specific chronology, but methods which allow the integration of human abstract pattern recognition are essential.

The first area to warrant development of a special chronology interface was that of bottleneck identification. Currently, bottleneck regions are identified by performing a simple analysis of changes in the number of conflicts on the schedule resulting from scheduling activity on a specific schedule segment. The user interface supports more sophisticated analysis by: 1) monitoring specified chronology parameters, 2) performing trend analysis to indicate how the parameters are changing, and 3) presenting this information to the user in alternative formats.

Heuristics and Guidance

The OMP user interface must enable the user to interact with the scheduling heuristics. Our method of accomplishing this is through a real time edit capability. While the scheduler is operating, the user will be able to interrupt the scheduler to modify parameters associated with the control heuristics. This ability to "tweak" the system will provide greater control over the system and will serve as a test and evaluation aid.

This approach, however, has limitations. The heuristics must be defined in such a manner that their parameters are easily accessible and special safeguards must be incorporated to avoid causing system errors [Arens 1988]. The user must be provided with an understanding of how the heuristics work and the significance of the parameters in order to make meaningful changes. For an operational system, this places a heavy burden upon the

user interface, and requires additional effort in defining heuristics. For the development phase, however, this overhead can be reduced.

Human guidance to the system can range from focusing the efforts of the scheduler on a particular segment of the schedule, to changing the pool of allowable heuristics for a scheduling pass, to providing specific instructions for a given task which differ from those originally provided (e.g. relaxing or adding constraints). At their most basic level, these forms of guidance can be thought of as editing existing definitions of tasks, resources, and heuristics. However, these editing tasks apply to a combination of data objects (tasks, resources) and processes (heuristics). Therefore, there is an overhead cost in the object representations associated with providing these editing features.

The scheduler must be able to interpret the relevance of a real-time edit to the original description of the object [Seeley 1987]. For example, if a user specifies that a task is to be assigned to a specific resource, is the scheduler allowed to disregard that assignment? If it does and the user once again makes that specific assignment, should it take the user more seriously? How does the scheduler know and interpret the level of preference? How do we help the user to provide this information?

In order to implement this edit feature, a temporary specification, or overlay, of an object description is used. Since OMP uses objects to represent tasks and resources, consistency must be maintained and inheritance features addressed when making temporary changes to an instantiation of an object type [Brachman 1985]. This overlay structure allows the system to operate using a modified description of an object, but does not remove the original specification which may be needed in later planning phases. The system can thus discard the overlay when it is no longer needed, does not have the overhead associated with creating and maintaining an overlay unless one is needed, and retains the original information during the scheduling pass affected by the overlay. A relative

preference scale which indicates the importance of a given user action, as well as methods for manipulating such a scale by both the user and the scheduler, are planned.

Assessment of the Schedule

Assessment of the schedule in progress is an important aspect of the iterative planning process. In order to identify when to progress to the next phase, the scheduler needs to assess the effectiveness of continuing in the current phase. Such indicators as level of effort expended without additional conflict resolution, the appearance of cycles in the scheduling actions, or the need to perform a substantial amount of deletion to resolve conflicts will be used to identify when to progress to the next phase. A more difficult problem, however, is assessing the quality of the developed schedule.

In our problem domain, determining the quality, or "goodness", of the schedule is exacerbated by a lack of specific metrics upon which to base an assessment. The OMP problem domain, for example, is highly oversubscribed. Therefore, there is no schedule which can perform all of the requested tasks. The tasks themselves follow a strict and absolute priority ranking, so the sheer number of tasks performed is not an effective metric. Nor is there a metric which relates numbers of tasks with different priorities. OMP requirements dictate minimization of the number of tasks not performed, but not at the expense of the higher priority tasks.

The development of evaluation criteria will be an important aspect of future OMP research. There are user interface features which will assist the user in developing these criteria. Statistical comparisons of the numbers and distributions of requested tasks vs. those actually incorporated into the schedule can be developed. Response times, resulting performance, and changes in configurations caused by responses to events can all be monitored and made available for off-line analysis. Incremental information in these areas will be available during the scheduling

process. These methods do not solve the problem of determining the characteristics of a good schedule. Rather, they perform an information gathering function which can be used to develop that definition.

Data Overload

The amount of information available to the user at any given time in the scheduling process can quickly become overwhelming. Special care must be taken to present information in an efficient fashion which permits the user to easily interpret the data [Tufte 1983]. Graphics and icons have become a popular means of representing data, but an appropriate level of abstraction must be selected. In OMP, for example, the tasks, in their most simple representation, are in the form of Gantt Charts. Unfortunately, the capacity of the screen is rapidly exceeded due to the sheer number of tasks which must be displayed.

Various "rich coding" and filtering techniques are used to reduce the visual confusion but maintain the level of information presented. Rich coding algorithms allow data to be represented at different levels of resolution or abstraction so that the user has a more intuitive grasp of the information presented without being overwhelmed by its magnitude.

Intent driven display techniques can also be used to reduce data overload [Madni 1982]. The information the user sees is filtered based on the task being performed. The user is spared from searching through potentially large amounts of extraneous data. Intent driven displays can interact with rich coding algorithms by setting the level of abstraction/resolution that these algorithms provide.

CONCLUSION

The types of interface features described in this paper present a departure from the basic paradigm of the user as a monitor of the planning system, rather than a participant in the planning process. In order for planning technology to progress to the point where it

can be effectively automated, the issues discussed in this paper must be addressed. While the user interface concepts are from the perspective of an integrated human-computer scheduling system, the user is, in essence, acting as a heuristic. Therefore, in order to automate those human-heuristic functions, they must first be identified and generalized. It is necessary to understand where, when, and how the human user can have a positive impact upon the scheduling process. Only then is it feasible to address advanced automation.

Several of the techniques discussed in this paper are now being used in the Operations Mission Planner. The existing OMP prototype incorporates the Initial Load, Resource Centered, and Time Centered Phases of the iterative planning process. The user interface is in a preliminary state and uses graphics to represent the state of the schedule as it is in progress. Insights into the planning process itself, as discussed in this paper, and advanced presentation techniques such as rich coding and intent driven displays are planned additions to the interface.

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